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An Overview of Postharvest Biology and Technology of Fruits and Vegetables

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Abstract

Harvested fresh fruits and vegetables are living products. They are characterized by high moisture content, active metabolism, and tender texture; as a consequence, significant losses resulting in senescence, desiccation, physiological disorders, mechanical injuries, and microbial spoilages occur at any point from harvest through utilization. The main objective of postharvest technology is to restrict deterioration of produce along the postharvest chain, and to ensure that maximum quality value for the produce is achieved. Temperature management and dehydration control are the essential and the two most important strategies to extend shelf life and retain quality of horticultural perishables. The other supplements such as controlled atmospheres and modified atmospheres, 1-methylcyclopropene fumigation, and heat treatments can further enhance their storability. Over the past few years, development and application of effective, safe, and environmental-friendly postharvest technology for edible horticultural commodities have become and will continue to be the number one concern by fresh produce handlers and consumers.

Introduction

Fruits and vegetables are considered as a commercially important and nutritionally essential food commodity due to providing not only the major dietary source of vitamins, sugars, organic acids, and minerals, but also other phytochemicals including dietary fiber and antioxidants with health-beneficial effects. In addition, fruits and vegetables provide variety in color, shape, taste, aroma, and texture to refine sensory pleasure in human's diet. There is an increasing demand for fresh produce at the consumer level, because of the raising awareness of people about the superior of fresh, natural foods than processed products resulting in the active encouragement by health agencies and public media as well as several medical researches demonstrating various health benefits of fresh produce consumption[13]. Fruits and vegetables, unfortunately, are highly perishable in nature and may be unacceptable for consumption if not handling properly following harvesting[3,4,7,13]. Furthermore, fresh horticultural products are important items of international commence after the globalization of trade and free trade agreements. Longer shipments and distribution periods may eventually increase the potential of heavy losses; therefore, the importance of proper cares and techniques for handling fresh produce after harvest has been recognized and emphasized. **Postharvest**, the connecting link between the grower and the

consumer, is concerned with the biology of harvested plant materials and uses this knowledge to develop effective and feasible handling technologies that delay the rate of senescence[3,13]. The main purposes of applying postharvest technology to harvested fruits and vegetables are to diminish losses between harvest and utilization, to maintain best possible quality (appearance, texture, flavor, and nutritive value), and to ensure food safety [3,4,13].

All fresh fruits and vegetables are living tissues. Due to high moisture content, active metabolisms, tender nature, and rich in nutrients, they are vulnerable to dehydration, environmental stresses, mechanical injury, and pathological breakdown and are usually considered to be highly perishable[3,4,7,13]. These characteristics strongly limit the storage life of fruits and vegetables and cause significant deterioration following harvest. Postharvest losses can occur at any point in the production and marketing chain. It is estimated that the magnitude of these losses due to inadequate postharvest handling, transportation and storage in fresh fruits and vegetables is relatively higher, 20-50%, in developing countries when compared to 5-25% in developed countries[4]. Kader (2005) commented that complete elimination of postharvest losses may be impossible and uneconomical, but to diminish them by 50% is possible and desirable[5]. Minimizing postharvest losses of produce that has invested substantial labor, materials and capital to grow is a very effective way to increase food availability without further boosting crop production[4,13]. To reduce these losses, understanding the causes of deterioration in fruits and vegetables is the fundamental step, and followed by utilizing appropriate and affordable technological procedures to delay senescence and conserve quality of produce. In this paper, the factors involved in deterioration of harvested fruits and vegetables are discussed first, and then some postharvest technologies generally used in the commodities are briefly summarized.

Factors Involved in Postharvest Loss of Fruits and Vegetables

The actual causes of postharvest loss in fresh fruits and vegetables are many and commodity specific, since horticultural products are diverse in morphological structure, composition, developmental stages, and general physiology[13]. However, the main causes of produce deterioration are continuous metabolism and growth, water loss, physiological disorders, mechanical damage and pathological breakdown[3,13].

1. Continuous Metabolism and Growth

Since fruits and vegetables are living biological systems, they are subject to metabolic and developmental changes even after harvesting. It is well established that the quality of the harvested commodities cannot be improved further but it can be retained till their consumption if the rate of metabolic activities are reduced by adopting the appropriate postharvest handling operations. One of the important parameters determining the metabolic activity of a horticultural product is its respiration rate, which is usually associated with the commodity deterioration. **Respiration**, involving enzymatic oxidation of organic substrates with energy production resulting in O_2

consumption and CO_2 and water production, represents sum of total of all the metabolic activities of the tissue[3,5,7,13]. Respiratory rate of produce after harvest is reversely proportional to its storage life, i.e., the higher the rate of respiration, the shorter is the storability, because the produce is detached from its source of photosynthates and is entirely dependent on its own food reserves[5,7]. Respiration rate of a produce is dependent on a wide range of variables, including commodity and environmental factors[3,5,7,13]. Among the external factors affecting respiratory rate of fresh fruits and vegetables after harvest, temperature is considered the most important in modulating this physiological parameter[3,5,7,13]. **Temperature quotient (Q_{10})**, which is the ration of the rate of a reaction at one temperature (T_1) versus the rate at that temperature plus 10℃ [(rate at $T_{1+10℃}$)/rate at T_1], is the measure usually quoted for respiration to give a general estimation of the effect of temperature on the overall metabolic rate of produce[5,7,13]. Within the 5℃ to 25℃ range, the velocity of respiration increase 2 to 2.5 folds for every 10℃ rise in temperature for most harvested produces, i.e., Q_{10} = 2.0-2.5. The gas composition, such as O_2, CO_2, or ethylene, surrounding the horticultural produce, also exerts a great impact on both its respiratory and general metabolic rate. The postahrvest technologists are mainly concerned with slowing down the rate of respiration for maintaining quality and maximizing storage life.

Ethylene, the simplest olefin, is a gaseous phytohormone that can significantly elicit the respiration and senescence processes of a number of harvested fruits and vegetables in trace amounts (less than 0.1 μL L^{-1}) [3,7,8,11,13]. In higher plants, ethylene is produced from methionine via three enzymatic reactions: (1) methionine is converted to *S*-adenosyl-L-methionine (*S*-AdoMet) by *S*-AdoMet synthetase; (2) the conversion of *S*-AdoMet to **1-aminocyclopropane-1-carboxylic acid (ACC)**, the immediate precursor of ethylene, is the rate-limiting step catalyzed by **ACC synthase (ACS)** in this pathway; (3) **ACC oxidase (ACO)** degrades ACC to release ethylene[8,11,13]. The major physiological responses regulated by ethylene in harvested horticultural products include chlorophyll degradation, fruit ripening, senescence, and abscission of plant organ[3,8,11,13]. Since exposure to ethylene can be detrimental to quality of most fresh horticultural commodities, ethylene is of major concern to all produce handlers during postharvest period.

Ripening is a developmental phase spanning from the last stage of maturation through the earliest stage of senescence in fleshy fruit and is commonly observed in many fruit products after harvest[1,,3,7,11,13]. It is widely accepted that fruit ripening is a senescence process, due to a breaking down of the cellular integrity of the tissue[1,7,13]. Several biochemical and physiological events involving in change of color, firmness, flavor, and aroma take place in this transitional period, which results in the transformation of unripe fruit into an edible ripe product[1,3,8,11,13]. Based on whether or not they produce a peak in respiration, the ripening behavior of fruits has been categorized as being either climacteric or nonclimacteric[1,3,7,13]. **Climacteric fruit**, such as apple, banana, and tomato, is defined by the dramatic increase of respiration rate and ethylene release during ripening. **Nonclimacteric fruit**, such as citrus, grape, and strawberry, on the other hand, displays a steadily decline in the respiratory pattern without significant enhancement of ethylene

production in this stage. This physiological behavior of the fruits has a great importance in the postharvest biology and technology of these commodities. For example, to obtain greater degree of storage and marketing flexibility, climacteric fruit is usually harvested at mature green (unripe) stage since it can ripen normally after harvest. Conversely, nonclimacteric fruit must be harvested only when fully ripe. Several lines of evidence have demonstrated that ethylene is the crucial phytohormone regulating timing of ripening in climacteric fruits[1,3,11]. Although nonclimacteric fruits typically produce little ethylene after harvesting, many have still been shown to be affected by exogenous ethylene during storage. As a consequence, ethylene control is a target for shelf-life manipulation for both climacteric and nonclimacteric fruits[3,11,13].

Active resumption of growth in harvested produce, such as sprouting and/or rooting of tuberous and bulbous crops, elongation and curvature of stem vegetables, and seed germination inside fruits, is undesirable and lead to great reduction in market quality and accelerated deterioration.

2. Water Loss

Fruits and vegetables typically contain 80-90% water in fresh weight basis[3,13]. Severed plant organs are much more susceptible to water loss, because the water replenish system is eliminated at harvest. As little as 5% loss in water has adverse effects on appearance, salable weight, and texture quality of many perishable commodities; therefore, the desiccation resulting from moisture loss is a main cause of deterioration during postharvest. **Transpiration** through stomata is the major way of moisture loss in fresh horticultural commodities[3,7,13]. The other paths of water loss are stem scare, lenticels and the cracks resulted from mechanical injury.

Produce characteristics, namely morphological and anatomical characteristics, surface area/volume ratio, surface injury, and maturity stage influence transpiration rate. For example, products like leaf vegetables with a large surface to volume ratio will lose greater percentages of their water far quicker than large spherical fruits. Loose leafy lettuce loses water more rapidly than head lettuce. Beside commodity factors, the rate of postharvest water loss is dependent primarily on the external **vapor pressure deficit (VPD)**, though other environmental factors will influence the situation[3,7,13].

3. Physiological Disorders

Physiological disorders of fruits and vegetables arise from exposure of the commodities to undesirable postharvest and preharvest environmental conditions or mineral imbalance arising during growth[3,7,13]. Low temperature-related, respiratory and nutritional disorder are particularly problematic.

The improper temperatures may lead to the disturbance in the normal metabolism of the harvested products. **Chilling injury (CI)** by low (< 10-13℃) but non-freezing temperature is

observed common with tropical and some subtropical origin fruits and vegetables[3,7,12,13]. Potential symptoms of CI are surface lesions, external and internal discoloration, water-soaking of tissues, abnormal ripening, and accelerated decay. The symptoms of CI may not be evident while the produce is held at chilling temperature but becomes noticeable only after being transferred to room temperature. **Freezing injury**, on the other hand, results from holding the commodities below their freezing temperatures[3,7,13]. The damage from ice crystals formed in tissues usually results in immediate collapse of the tissues and total loss of the commodity.

Nutritional disorders originate from preharvest mineral imbalance are sometimes appear only after harvest in products. Calcium is associated with more postharvest-related deficiency disorders than any other mineral[3,13]. **Bitter pit of apples** and **blossom-end rot of tomato** are well-known calcium deficiency disorders in horticultural crops[3,13]. Respiratory disorders are associated with very low O_2 (< 1%) and/or high CO_2 (> 20%) concentrations in and/or around harvested produce in storage or packaging condition[3,5,13].

4. Mechanical Damage

Mechanical damage of fruits and vegetables, as a consequence of inappropriate harvesting and postharvest handling, is one of the most common and severe defects of horticultural products. It not only directly affects appearance attributes (skin and flesh lesions and browning) but also creates sites for pathogen infection and water loss. Furthermore, physical injury stimulates ethylene production and respiration in plant tissues, which can lead to acceleration of senescence[3,7.13].

5. Pathological Decay

As mention above, fruits and vegetables are characterized contain a wide range of organic substrates and high water activity, and thus are good substrates for microbial spoilage. Accordingly, a significant portion of losses of fresh produces during postharvest is attributed to diseases caused by fungi and bacteria[3,7,13]. The acidic tissue of fruits leads to their spoilage being predominately by fungi, whereas vegetables having pH above 4.5 are commonly attacked by both bacteria and fungi. The most common pathogens causing decays in fruits and vegetables are species of the fungi *Alternaria*, *Botrytis*, *Botryosphaeria*, *Collectotrichum*, *Diplodia*, *Monilinia*, *Penicillium*, *Phomopsis*, *Rhizophus* and *Sclerotinia* and of the bacteria *Erwinia* and *Pseudomonas*[13]. Fruits and vegetables generally possess considerable resistance to potential pathogens during most of their postharvest life. Senescence, ripening, or stresses, e.g., mechanical damage and chilling injury, may render them susceptible to infection by pathogens[3,7,13]. Although most pathogens totally rely on physical injury or physiological breakdown of the commodity to invade host tissues, a few such as *Colletotrichum* are capable to actively penetrate the skin of healthy product[3,13]. Mirobial infection can occur before and/or after harvest. **Latent infection**, or **quiescent infection**, is the state in which a product is infected prior to harvest with

no obvious symptom developing until the pathogens are reactivated by onset of conducive conditions, such as fruit ripening or favorable temperatures. Diseases with latent infection, e.g. anthracnose diseases of tropical fruit caused by *Colletotrichum gloeosporioides*, often causes rapid and sever postharvest decay since the infected produce cannot be sorted out easily before storage[7,13].

Technologies to Improve Postharvest Quality

The main objective of postharvest technology is to restrict deterioration of produce as much as possible along the postharvest chain, and to ensure that maximum market value for the produce is achieved. The technologies involved in postharvest handling of fruits and vegetables are enormously complicated because the products are divergent in their structural origin, developmental stage, and physiological status, and perishability[7,13]. However, to protect the harvest products by proper packaging, minimize their respiration rates and developmental events, such as growth or ripening, by low temperature storage, or manipulating their physiology, eliminating or suppressing microbial activities are the basis of all the postharvest techniques. Some commonly used and fundamental postharvest technologies are summarized below.

1. Temperature Management

Temperature management is the most effective tool for maintaining quality and extending the shelf life of fresh fruits and vegetables after harvest, as temperature affects the rate of most biochemical, physiological, physical, and microbiological reactions contributing to postharvest deterioration[3,7,13]. Thus, storage at low temperature has been the main strategy to preserve harvested horticultural products[3,7,13]. The major effect of the low temperature application between harvest and end use is a reduction of the produce metabolism and consequently a delay of the evolution of the parameters related to quality loss and senescence. Typical Q_{10} values within the physiological temperature range for deterioration are approximately 2 to 3 for most horticultural products[5,7,13], implying that storability would be double or triple for every 10℃ reduction.

It is necessary not only to chill the harvested product but to cool it as quickly as possible in order to maintain the commodity as close to its condition at harvest. **Precooling** is a process that removes field heat from freshly harvested products by a cooling treatment before shipment, storage or processing[3,13]. Because of slowing down the rates of their respiration and water loss, as well as the growth of decay microorganisms around, prompt cooling after harvest is desirable for retarding the deterioration of fruits and vegetables, especially when harvesting was conducted during hot weather. The beneficial effects of precooling on prolonging shelf life is more pronounced in metabolically active and highly perishable products, such as small berry fruits, flower and stem vegetables[3,7,13]. The major precooling methods include room cooling, forced-air cooling, hydrocooling, packaging-icing, and vacuum cooling, each one having different advantages for each particular produce and/or practical applications[3,13]. **Forced-air cooling**,

involving pushing cold air down by an induced pressure gradient through packages and around each item of produce, is adaptable to a wider range of commodities than any other cooling method.

After precooling, the produce should be directly transferred to storage at the optimum temperature, which is usually just above that which will cause chilling or freezing injury. Refrigeration or low-temperature storage has been considered the most efficient method to retain quality of most fruits and vegetables due to its effects on reducing respiratory rate, water loss, ethylene emission, senescence and microbial spoilage. However, the use of refrigerated storage is limited by the chilling sensitivity of many products and by its cost occasionally[3,7,12,13].

Temperature management begins with the time of harvesting[3,13]. It is often good practice to harvest during the coolest part of the day to reduce product warming. Protect harvested produce from exposure to direct sunlight when accumulating fruits or vegetables in the field; then rapidly deliver them to packinghouse for precooling. An unbroken **cold chain** throughout the postharvest handling system is essential to extend and ensure the shelf life of horticultural perishables[3,13].

2. Control of Water Loss

The basic principle of minimizing water loss from fruits and vegetables during postharvest period is to decrease the capacity of surrounding air to hold additional water[13]. It can be achieved by commodity treatments, such as surface waxing or coating and plastic film wrapping, or by environment manipulations, such as reduction of VPD between the product and air via lowering temperature and/or raising **relative humidity (RH)**, or control of air movement[3,7,13]. Despite the fact that maintenance of a high relative humidity atmosphere is necessary to arrest water loss, very high RH (> 95%) can encourage the proliferation of bacteria or fungi and, therefore, pathological breakdown. In general, it is recommended that 90% and 98-100% RH are the optimal compromise condition for fruit and leafy vegetable storage, respectively[3,13].

3. Atmosphere Modification

Alternation in the concentrations of the gases around horticultural products can significantly increase their storage life, resulting from reduction in respiration rate of produce, retardation of senescence, and growth inhibition of many spoilage microorganisms. The terms **controlled atmospheres (CA)** or **modified atmospheres (MA)** refer to create an atmospheric composition around the produce which is different from normal air by addition or removal of gases[3,6,13]. The levels of O_2, CO_2, N_2 and ethylene in the atmosphere may be manipulated. In practice, CA and MA usually involve reducing O_2 levels below 5% and/or elevating CO_2, levels above 3%[6]. The only difference between CA and MA is that the gas control is more precise in CA than in MA[3,6,13]. The tolerance or susceptibility of produce to the injury caused by decreased O_2 and increased CO_2 concentration is an important factor for successful development of CA and MA technology. **Modified atmosphere packaging (MAP)** is an alternation in the composition of gases

surrounding fresh produce by respiration and the aid of plastic films with selective permeability to the gases[3,6,13]. Recently, a rapid expansion of MAP has occurred for minimally processed (fresh-cut) fruits and vegetables. The beneficial effects of CA and MA storage include prolonged storability of perishables by arresting respiration and senescence, reduction in ethylene biosynthesis and sensitivity of produce, decrease in incidence and severity of decay and control of fungi, bacteria and pests in selected commodities. However, when used incorrectly, the potential harmful effects of CA and MA technology are aggravation of physiological disorder, irregular ripening of fruits, development of off-flavor, and increase of susceptibility to decay[3,6,13]. The difference is often very small between beneficial and harmful CA and MA combination. In addition, CA and MA are considered as an adjunct to refrigerated storage and not substitutes for proper temperature and RH management[3,6].

4. Treatments to Reduce Ethylene Damage

The presence of ethylene in the atmosphere has been a major concern not only for unripe climacteric fruits but also for non-climacteric fruits and vegetables during the postharvest handling, because it accelerates ripening, senescence, abscission and physiological disorders[3,7,11]. The action of ethylene must be avoided for most horticultural products during storage and transportation; therefore, technologies to limit the ethylene biosynthesis of tissue, fast remove emitted ethylene from the surrounding atmosphere of produce, and create the environment of storage unfavorable for ethylene action are utilized widely in commercial practice[13]. A simple physical method to prevent ethylene accumulation is to ensure good air circulation inside the storage room and ventilation with external air if needed[13]. Ethylene absorbents, such as potassium permanganate on vermiculite in packages have been tried with success to oxidize the ethylene release from fresh products[13].

Recently, the successful registration and commercialization of **1-methylcyclopropene (1-MCP)** for application in edible horticultural products has opened an exciting new era of reducing ethylene damage in marketing quality and storage life of fruits and vegetables after harvest[2,10,13]. 1-MCP is an antagonist of ethylene responses and acts by occupying ethylene receptors such that ethylene cannot bind and its signaling is blocked[2,13]. The positive chemical attributes of 1-MCP as an odorless gas, active at very low concentrations, persistent effects, nontoxic mode of action and negligible residue have led to intense interest as a commercial technology.

5. Heat Treatment

Nowadays there is an increasing awareness among consumers that the chemical treatments of fruits and vegetables to control pests, pathological microorganisms, and physiological disorders are potentially harmful to human health and environment, there is a trend towards the use of natural compounds or physical treatments for insect disinfestations and disease control in fresh

horticultural produce[3,9,13]. Heat treatments have actually been considered as environmentally friendly methods of deterioration control, either alone or in combination with other methods. The most common used heat treatments include hot water immersion, forced-hot air treatment, and vapor heat treatment[9]. Hot water immersion has been used classically for fungal control and vapor heat treatment was developed specifically for insect control, while forced-hot air treatment is used for both fungal and insect management[9].

The tolerance of produce to heat treatments must be carefully evaluated, since the inappropriate heat treatments leads to heat injury. The fact that the condition difference between beneficial for quality maintenance and causing damage to the commodity under treatment is a matter of only a few degrees has strongly impeded the scale-up application of heat treatments[9,13]. The threshold temperature and uniformity in space throughout the entire duration of the process are the two most important factors that should be taken into account during heat treatment process development on an industrial scale.

Concluding Remarks

In conclusion, today fresh produce consumers are not only looking for traditional quality attributes such as appearance, firmness and flavor, but also value other parameters, including nutrients and bioactive compounds availability, antioxidants, and aroma. There is growing concern about food safety and environmental issue. Therefore, a major goal for postharvest handling of horticultural products should emphasize on both effective preservation of the quality attributes already mentioned and the use of appropriate technologies considered to be safe and low or no adverse environmental impact[3,13].

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